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13. ABSTRACT (Maximum 200 words)

The motivation for this research was to investigate the possible role of self-organization, the development of long-range order from short-range nonlinear processes, in nearshore processes. Self-organization models for subaerial and subaqueous ripples, bedforms and beach cusps were developed and a field experiment was conducted to test the model for beach cusp formation against a standing wave model. The models indicate that ripples and other bedforms are well-characterized as attractors, wherein their pattern-scale characteristics are insensitive to the detailed flow and sediment transport dynamics. Measurements during beach cusp formation are in qualitative and often quantitative agreement with a self-organization model, but are not in agreement with a standing edge wave model.

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FINAL REPORT:
Young Investigator Award and
Swash Zone Morphology: Field Manipulation and Simulation

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These awards supported research on modeling small-scale nearshore morphology and tests of two models for beach cusp formation. The motivation for this research was to investigate the possible role of self-organization, the development of long-range order from short-range nonlinear processes, in nearshore processes. Self-organization models for subaqueous ripples, bedforms and beach cusps were developed and a field experiment was conducted to test the model for beach cusps against a standing edge wave model. Some of the analysis of the data from the experiment was supported by a subsequent award (Nearshore Processes as Complex Systems) and some support to undergraduate salaries was provided by an AASERT award. Some logistical support was provided by the staff of the Army Corps of Engineers Field Research Facility.

Ripples
A model for the initial formation and evolution of subaqueous ripples was developed to address the following questions: (i) can ripples initially form with the positive feedback for growth being the lowered flux over tilted surfaces, as in the case of eolian ripples, or is an asymmetrical modification of the fluid flow around incipient ripples required; and (ii) by what mechanism do ripples grow once initiated?

The model treats the fluid as nominally inviscid, using a modified two-dimensional panel method to calculate flow in the presence of moving circular particles. The particles interact through contact forces that include stiff normal forces and friction. The particles are coupled to the fluid by a velocity-dependent drag force. Ripples do not form in this model from an initially flat bed; finite-amplitude ripples decay rapidly.

Introduction of an artificial asymmetry of sufficient magnitude in the flow speed around a bump on the surface robustly leads to formation of propagating ripples from initial random surface bumps. These ripples do not grow in amplitude by upstream offset of the flux profile from the surface profile, as in conventional linearized models for ripple formation. Rather, they grow in spacing and amplitude by merger between ripples, as illustrated in the sequence shown below.

Bedforms as Attractors
A question pertaining to modeling the formation of all types of bedforms is the following: what is the minimal distillation of complicated sediment transport and fluid flow properties required for a

model that reproduces natural behavior of bedforms? For the simple case of eolian dunes, the provisional answer appears to be that much of the rich behavior and patterning of dunes can be reproduced with nearly any (non-pathological) transport algorithm that causes sediment to form into smooth clumps that migrate and communicate lateral to the transport direction (Werner, 1995). These simulated dune patterns are consistent with being attractors, states to which the system evolves from a broad range of initial conditions, in the space of variables characterizing the large-scale properties of the dune pattern. The potential significance of this finding is that nonlinear, dissipative systems near attractors can be organized into a hierarchy of variables, ordered by time scale. This provides an objective means of evaluating and testing hypotheses for dynamically important variables and processes for use in models. These ideas are now being applied to nearshore bedforms such as megaripples, larger-scale nearshore bathymetric features and nearshore hydrodynamics in research supported by subsequent Office of Naval Research grants.

Beach Cusp Models

In contrast to a long-standing edge wave model, a numerical model for formation of beach cusps was developed in which beach cusps initiate when convergence of flow of the swash in depressions in the beach causes erosion and divergence of flow over bumps causes deposition and beach cusps stabilize through the increase in beach surface curvature as beach cusps grow (Werner and Fink, 1993). In the model, swash flow is modeled by a line of quasi-independently acting water particles, nominally representing the swash front, that move on the surface primarily in gravity and erode, transport and deposit slabs of sediment that comprise the beach. The collapse of a bore into a swash tongue that moves up and down the beach is simulated by projecting the water particles up the beach with a given velocity. The model results in beach cusps that are realistic in form and in spacing. This self-organization model cannot be discriminated from the standing edge wave model through measurements of beach cusp spacing, given current uncertainties in both models, because the predictions of the two models are related by saturation of swash flow in the sea/swell band and are approximately equal.

The model has been extended to include swash flow initiated with statistics characterizing realistic, irregular collapsing bores, which can be taken from measurements. These simulations lead to smoother, less regular beach cusps. Under obliquely directed swash, beach cusps can migrate against the longshore current if swash flows over the horns.

Additional of a tidal signal to the location for launching the water particles up the beach results in beach cusps of greater extent in the cross-shore direction and with horns that are less blunt, in rough accordance with observations. As the tide rises, beach cusp height lower on the beach diminishes as horns below the swash zone are eroded and bays below the swash zone are filled by deltas as a result of the asymmetrical circulation pattern within beach cusps. As the tide lowers, these diminished beach cusps are re-formed by the self-organizing interaction between swash flow and morphology.

The model also was modified to include the effects of infiltration, groundwater flow and exfiltration on a porous beach. With these effects, as the tide rises, infiltration on a dry beach leads to preferential deposition in beach cusp bays (where swash flow is directed) and consequent decreasing beach cusp height. On falling tide, the pattern is reversed, with preferential exfiltration

and erosion from bays leading to increasing beach cusp height.

Testing Beach Cusp Models
The standing edge wave and self-organization models for beach cusp formation are the only two existing models that make predictions that permit quantitative testing. Following the conclusion that the models make similar predictions for spacing and formation conditions, it was necessary to design a set of tests and measurements in which discrimination was possible. The two models make differing predictions for the pattern of swash flow during beach cusp formation. Therefore, a set of seven experiments were conducted on a beach at Duck, NC in 1994 (ACOE Field Research Facility) in which morphology was measured by theodolite surveys, swash flow was measured from videotape images, and waves and currents were measured with pressure sensors and current meters in the surf zone (for some of the experiments). In one experiment, beach cusps formed after a storm smoothed the beach. In the other six experiments, a section of beach was smoothed and/or morphological features including channels and bumps were artificially created on the beach using a bulldozer.

In all experiments but one (in which there were no beach cusps on the beach prior to the experiment), some type of cuspate morphology developed Three relatively clean formation events (two in which the beach was smoothed by bulldozer, one in which the beach was smoothed by a storm) were chosen to test the two models. The results indicate that the qualitative pattern of swash flow predicted by the self-organization model, flow on horns leading that on bays with increasing magnitude as beach cusp height increases, was observed in the measurements. Least squares fits to a linear sum of predictions from the two models indicate that best fits to the measurements are given with a standing edge wave amplitude equal to 0cm (in most cases), with uncertainties generally under 5cm, far smaller than the ~0.5m high beach cusps that formed. In many cases, the quantitative predictions for swash flow of the self-organization model were within uncertainties of measurements; however, it is clear that the simple water particle model does not capture all aspects of swash flow.

The self-organization model (without groundwater flow) reproduces the basics of beach cusp formation, including spacing, general shape and time for formation of beach cusps. Addition of groundwater flow reproduces the observed asymmetry with rising and falling tides of beach cusp decay and growth high in the swash zone. Upper beach and lateral bathymetry were observed to exert significant influence on beach cusp formation in both model and measurements; the former because slow-moving swash near the peak of its trajectory is strongly influenced by morphological variations and the latter because of the converging or diverging influence of lateral morphology on swash flow. Several additional observations, including the changing direction of obliquely-pointing beach cusp horns, are continuing to be investigated with the model.

A qualitative observation from the experiments is that different beach cusps (even adjacent beach cusps) respond differently to the same changes in external wave and current conditions. This behavior could indicate that the state of the beach locally exerts significant influence on its subsequent evolution, because no two beach cusps have precisely the same morphology. This would point toward strongly nonlinear nearshore dynamics. It could also indicate slight variations in swash characteristics caused by offshore bathymetry. It is not yet clear whether the current data set will permit these two possibilities to be distinguished.

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